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MHAV: Multitier Heterogeneous Adaptive Vehicular Network with LTE and DSRC

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Abstract

Enabling cooperation between vehicles form vehicular networks, which provide safety, traffic efficiency and infotainment. The most vital of these applications require reliability and low latency. Considering these requirements, this paper presents a multitier heterogeneous adaptive vehicular (MHAV) network. Comprising of transport operator or authority owned vehicles in high tier and all the other privately owned vehicles in low tier, integrating cellular network with dedicated short range communications. The proposed framework is implemented and evaluated in Glasgow city center model. Simulation results demonstrate that the proposed architecture outperforms previous multitier architectures in terms of latency while offloading traffic from cellular networks.

Keywords: LTE; DSRC; Multitier; VANET; Heterogeneous; C-ITS

1. Introduction

Making vehicular networks (VANETs) heterogeneous allows us to complement one technology's drawbacks with another's advantages. For instance, dedicated short range communication (DSRC) cannot provide reliability due to the presence of obstacles despite providing low latency in direct communications [1]. At the same time, packet switched cellular networks can provide higher reliability with acceptable delays in message dissemination [2]. Use of cellular networks in VANETs, especially long term evolution (LTE) has been studied intensively in [3–7]. Previous studies have suggested the use of LTE by itself, exploring its functionalities such as multicast/broadcast multimedia systems (MBMS) and device-to-device (D2D) communications in order to cater for capacity.

There have also been studies which considered integrating LTE with DSRC. Remy et al. [7] in the pursuit of integration proposed group formation of vehicles forming clusters. The vehicles then communicate with each other and infrastructure via an elected cluster head. Similar to the concept of cluster head, authors in [8] proposed multiple communication hops to reach an elected high tier node classified as a gateway. This concept of group formation and a gateway selection results in high overheads and also privacy and security issues. A survey carried out in [9] showed that 35% out of 1533 road users from US, UK and Australia were concerned about privacy in regards to sharing their information with other road users.

In order to reduce the privacy and security concerns, authors in [10,11,3,12] using either DSRC, LTE or both access technologies, suggested the use of public buses and transport as gateways. The advantage is their frequent and fixed routes, resulting in a number of predefined parameters. Researchers in [10] proposed to use DSRC while employing multiple hops. Their proposed architecture also included a gateway registration technique, known as longest registration time algorithm

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Table 1
Related work on multitier heterogeneous VANETs.

Algorithm	Tier nodes	LTE-DSRC	LTE in all nodes	Clusters	Fall-back	Simulation Area	Application	Selection criteria	Performance metrics	Ref
BUS-VANET LRTA	Buses/ Private	No	No	Yes	None	Downtown Minneapolis, USA	Safety	Maximum delivery delay	Delivery Delay, Packet Loss	[10]
TPHVN	Buses, Taxis/Private	Yes (LTE D2D)	No	Yes	Clustering	Tianjin Nankai, China	Safety	Fuzzy score of vehicle type and traffic speed	Delivery Ratio, Delivery Delay	[11]
CMDS	Buses/Private	Yes	No	Yes	Clustering	Highway/ Grid model	Safety	Cloud decides using transmission range	Dissemination Delay	[3]
MHAV (Proposed)	Authority owned buses, taxis, lorries/private	Yes	Yes	No	LTE SAI [13]	Glasgow City Center, UK	Safety, Traffic efficiency and Infotainment	Relative velocity, location and transmission range	Delivery Delay, Packet Delivery, LTE/DSRC Offloading	–

(LRTA). Authors in [12] proposed using data aggregation techniques in collaboration with cloud computing over cellular networks while performance of the proposed scheme is not evaluated. Li et al. [11], proposed integrating LTE direct communications with DSRC. However, their work is based on predicting vehicle behavior using fuzzy score logic and then routing messages accordingly. Finally, Liu et al. [3] proposed a comprehensive cloud assisted downlink message dissemination scheme with public buses. In their proposed scheme, the cloud does most of the work in the form of delegating message forwarding in a predefined targeted area. Furthermore, they assume that only the buses would have LTE and DSRC integration, the rest of the vehicles would use DSRC only. The drawback for this framework, due to the absence of LTE interface in low tier vehicles, is the lack of internet connectivity and a fall-back mechanism.

In the light of previous works on multitier vehicular networks, contributions of this paper include:

1. A multitier LTE/DSRC integrated vehicular network architecture incorporating authority and operator owned vehicles known as Multitier Heterogeneous Adaptive VANET (MHAV).
2. Message dissemination technique employed for packet forwarding in the proposed MHAV framework, balancing the load between LTE/DSRC network.

The remainder of this paper is organized as follows: Section 2 describes the proposed multitier heterogeneous framework, and Section 3 elaborates on the system model followed by simulation results in Section 4. Conclusions and future work are then discussed within Section 5.

2. Multitier heterogeneous adaptive VANETs

The MHAV framework incorporates high tier nodes (HTN) and low tier nodes (LTN). HTNs are the authority or operator owned vehicles such as public buses, taxis, council lorries, etc. while LTNs comprise of all the other private vehicles. Both HTNs and LTNs are assumed to be equipped with LTE and DSRC interface, integrated with the help of a control device [14].

Data delivery in the proposed framework is carried out with the collaboration of HTNs, traffic control center (TCC) and vehicular safety application (VSA) server. The TCC and VSA are situated at the core of LTE network and are also accessible via internet. All the LTNs are registered with respective HTN, which then enable V2I and V2V communications. If an HTN is not available, LTN falls back to using LTE network. HTNs regularly update their tables via LTE from TCC server including information like the traffic conditions, their registered LTNs and neighboring HTNs. HTNs broadcast beacons every second consisting of their location, velocity and ID using DSRC. LTNs receiving these broadcasts run our proposed registration algorithm [15] in order to register with the most suitable HTN. Once the LTN is registered, all V2V communications are carried out via the registered HTN, acting as a message relay. The basic architecture of our proposed framework is shown in Fig. 1 and comparison with previous works is shown in Table 1.

Since all the traffic related information is updated in the TCC, LTNs which are not registered with HTNs can also access this information via LTE. As for the safety applications, we suggest the use of a differentiated quality of service (QoS) mechanism known as safety application identifier (SAI) described in [13] implemented via the VSA server. In the next subsection, we explain the proposed message dissemination technique implemented at the HTN.

2.1. Message dissemination technique

Since the presented framework does not use the concept of group formation, message dissemination technique would

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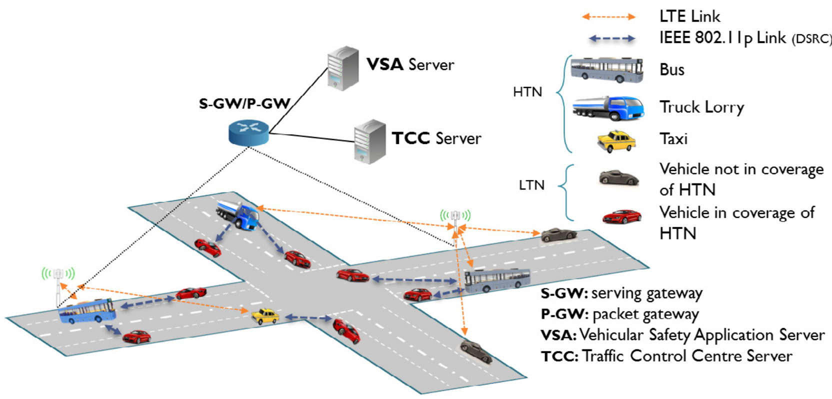

Fig. 1. Multitier Heterogeneous Adaptive VANET Framework with all possible scenarios.

require message relaying via the registered HTN. We use the concept of our previously proposed safety application identifier (SAI) which assigns different applications with their required transmission parameters [13]. Within the SAI algorithm, the message is transmitted in accordance with the awareness range[1] and beacon frequency requirements. Instead of using the LTE network, in our proposed framework, LTNs transmit messages to their registered HTNs. These HTNs then look up the LTN's location and SAI from the received message. The HTN then locates all the vehicles that are intended to receive the message using the retrieved SAI and awareness range. Using the table updates from TCC, if these receivers are registered with the same HTN, they receive the message over DSRC. However, if the vehicles are registered with another HTN, the message is transmitted to the respective HTN either over DSRC or via the LTE network if the other HTN is not in the transmission range of DSRC.

LTNs which are not registered with any HTNs, would fall back to using SAI over LTE network. Since the TCC and VSA are both located in a centralized LTE network, the forwarded message including the awareness range and transmission frequency would then be forwarded by the VSA to the respective receivers either via HTNs or directly via eNodeBs. The proposed message forwarding algorithm implemented on HTNs is shown in Algorithm 1.

Algorithm 1 HTN Message Forwarding Algorithm

Input: $VSMs : LTN \longrightarrow HTN$
R_i: Awareness Range of vehicle i
BF_i: Beacon Frequency
d_{ik}: Distance between vehicles i and k
$\mathbf{F}_i$: Forwarding Set containing all intended receivers for i
Output: $VSMs : HTN \longrightarrow LTN$
System Setup :
HTN maintains routing table with TCC and VSA
while $HTN \leftarrow VSM_i$ **do**
  TCC locates all vehicles
  TCC $\longrightarrow$ HTN
  $VSM_i \longrightarrow (SAI_i,\ Position(d_k))$
  $SAI_i \longrightarrow (R_i,\ BF_i)$
  $(R_i, d_k) \longrightarrow Distance(d_{ik})$
  $\mathbf{F}_i = \{\forall k : d_{ik} < R_i, i \neq k\}$,
  $HTN \Rightarrow LTN \in \mathbf{F}_i$ at BF_i
  if LTN not registered with HTN **then**
    Message forwarded to respective HTN
  end if
end while
return $\mathbf{F}_i$

3. System model

The network modeled is a 2×2 km^2 area of Glasgow's city center with varying density of vehicles evaluating both rush hours when there is high presence of HTNs and less busy hours with lesser HTNs available. Both LTNs and HTNs are assumed to be equipped with Frequency Division Duplex (FDD) LTE transceivers with 20 MHz bandwidth, uplink carrier frequency 1715 MHz and downlink carrier frequency 2115 MHz (band 4) [16, Table 5.5-1] integrated with IEEE 802.11p compliant DSRC interface operating at 5.9 GHz with 10 MHz bandwidth [17]. These nodes are assumed to be moving in urban model created using routes mobility model [18] on ns-3 [19]. Simulation parameters used are given in Table 2.

3.1. Performance measures

We compare our results with the previously proposed frameworks implemented in [10] and [3]. The primary performance measures used are the *End-to-end delay*, *DSRC coverage* and the *LTE Goodput*. The *end-to-end delay* is the time a packet takes from the transmitting LTN to the receiving LTN either via registered HTN or the LTE network. *DSRC coverage* is the percentage of LTNs registered with HTN, classified as the traffic offloaded from the LTE network. Furthermore, the *LTE Goodput* is the number of useful information bits received at the application layer per unit time.

4. Simulation results

Safety related applications form a vital part of vehicular networks. They also have stringent requirements when it comes to latency and reliability. Standards specify that a critical latency

[1] **Awareness Range** is the geographical area around the vehicle where all the neighbors are to be made cognizant of the vehicle.

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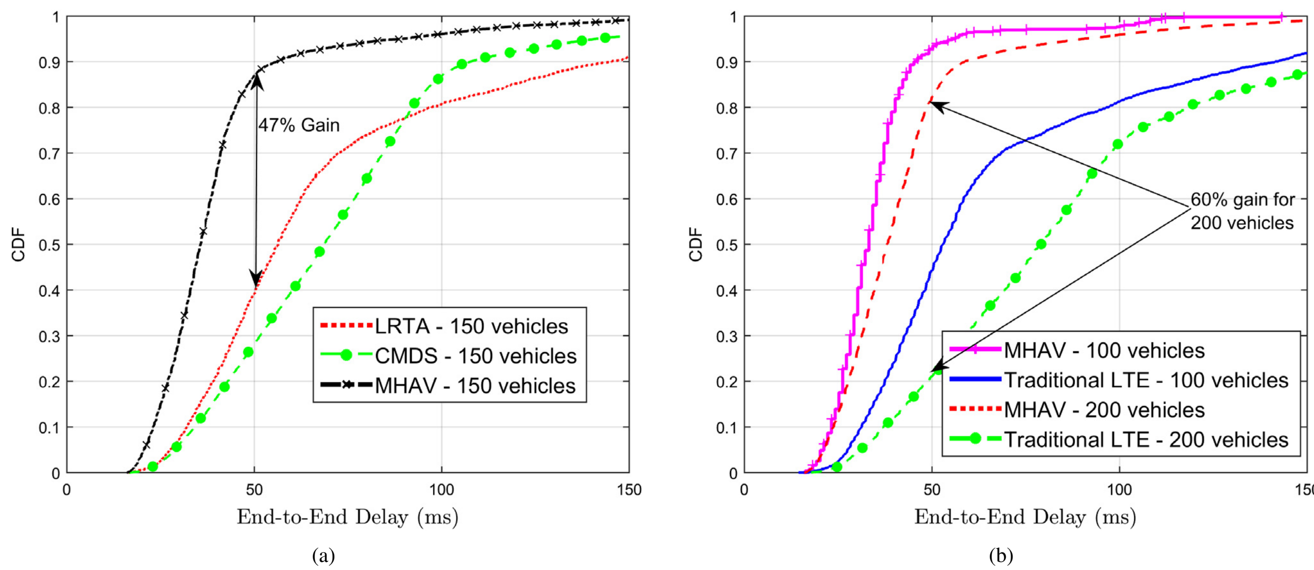

Fig. 2. End-to-end delay in an urban scenario and (a) Comparison with LRTA and CMDS, (b) Offloading of LTE traffic.

Table 2
Simulation parameters.

Parameter	Value
Simulation time	300 s.
Road model	2×2 km^2 Glasgow city center
Number of LTNs	100, 150, 200.
Number of HTNs	5, 10, 15.
Average vehicle's speed	20–30 mph.
Number of simulation runs	30.
DSRC	
Access technology	IEEE WAVE 1609 and 802.11p.
Propagation model	Nakagami and Friis Models.
Operating frequency	5.9 GHz.
Data rate	6 Mbps.
Transmission power	25 dBm.
Antenna	Omnidirectional.
Channel bandwidth	10 MHz.
Noise figure	7 dB.
CCA threshold	−86 dBm.
Sensitivity	−83 dBm.
LTE	
Network	6 sites with 3 cells/site, 1000 m ISD.
Transmission power	eNB: 40 dBm, UE: 23 dBm.
Carrier frequency DL/UL	2115 MHz/1715 MHz.
Channel bandwidth	20 MHz (100 RBs)
Noise Figure	eNB: 5 dB, UE: 9 dB.
UE antenna model	Isotropic (0 dBi).
eNB antenna model	15 dB Cosine model, 65° HPBW.
Scheduling algorithm	Proportional Fair.
Handover algorithm	A2A4RSRQ, RSRQ threshold −5 dB, and NeighbourCellOffset = 2 (1 dB).
Frequency reuse	Distributed fractional freq. reuse.
Path loss model	LogDistance ($\alpha = 3$) and 3GPP extended vehicular A model.

of less than 100 ms is required for successful implementation of vehicular networks [20], however, previous implementations have benchmarked their acquired latency at 50 ms [4]. In our proposed framework, LTNs carry out V2V and V2I communications via either HTNs or the LTE network, therefore, we evaluate the end-to-end latency experienced by every packet.

Fig. 2 shows the cumulative density function (CDF) for the end-to-end delay in our simulated Glasgow city center. Fig. 2(a) shows the comparison of our proposed MHAV framework with longest registration time algorithm (LRTA) [10] and cloud-assisted message dissemination scheme (CMDS) [3]. Probability of end-to-end delay being less than 50 ms for MHAV is 87% while for LRTA and CMDS its 40% and 30%, respectively. This significant increase in delay for LRTA is because of its fast changing topology in switching between HTNs. Whereas in CMDS it is due to the configuration time it requires to set up the cloud assistance. In the proposed MHAV, the dissemination technique used restricts communication within a certain awareness range according to the application requirements. This in return avoids capacity block due to message flooding both in DSRC and LTE, resulting in higher resources and eventually, lower delays.

Similarly, in Fig. 2(b), offloading of vehicular communications from LTE is evident. Implementation of MHAV with 100 and 200 LTNs in our simulation environment shows that the probability of delay being less than 50 ms increases from 44% to 93% for 100 LTNs and 22% to 82% for 200 LTNs. This is due to the fact that after MHAV implementation, evident from Fig. 3, 68% of LTNs now operate on DSRC via their registered HTNs enabling low latent direct communications while reducing the amount of traffic on LTE.

Fig. 3 shows how the LTE goodput decreases when the DSRC coverage increases. In MHAV framework, it is evident that increasing the number of HTNs from 10 to 30, increases the DSRC coverage area by 35%, eventually offloading 8 Mbps of traffic from LTE network. Therefore, it can be concluded that by having more transport operators or authorities involved, more number of HTNs are present thus reducing the amount of traffic on LTE and eventually enabling LTNs to communicate

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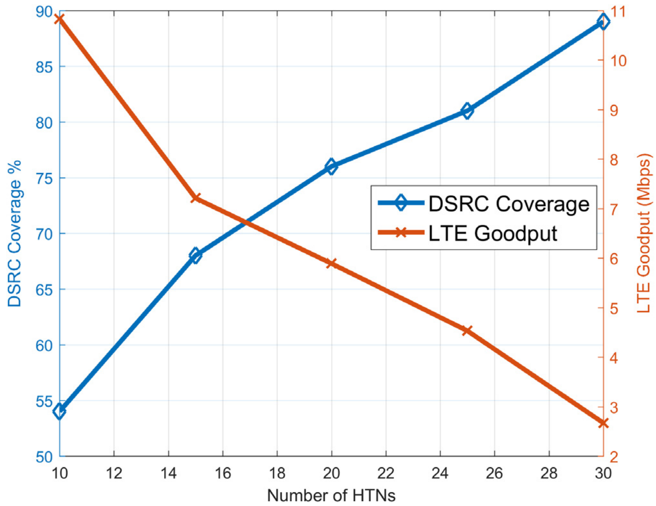

Fig. 3. DSRC Coverage and LTE Goodput vs. Number of HTNS for 150 vehicles.

with each other and the infrastructure via HTNs over DSRC instead of the LTE network.

5. Conclusion and future work

This paper proposes a multitier heterogeneous adaptive VANET framework and a message dissemination scheme. MHAV architecture consists of HTNs being authority owned or transport operator vehicles such as public buses, taxis, council lorries, etc. and LTNs being all the other privately owned vehicles. All the vehicles are assumed to have LTE and DSRC capabilities where LTNs register with HTNs to enable V2I and V2V communications over DSRC while the HTNs connect to the LTE network in order to provide infrastructure communications to its registered LTNs. A fall-back to a previously proposed LTE mechanism in the case where there is no HTN present for registration is also evaluated. Simulations are carried out in Glasgow city center which is a dense urban environment in order to evaluate the proposed framework. Results show that the proposed HTN message forwarding algorithm outperforms the traditional BUS VANET frameworks by 47% in terms of probability of end-to-end delay being less than 50 ms. This framework also offloads more than half of the vehicular traffic from cellular networks. Results also showed that by increasing number of HTNs, DSRC coverage increases while decreasing the amount of traffic on LTE network. Furthermore, having authority owned gateways tend to make the network more secured and also addresses the privacy issue raised by many private car owners.

In the future, we plan to evaluate other scenarios such as highways and suburban areas where some parameters in our algorithm are speculated to be significant for a robust network. We also plan on implementing proposed algorithms and techniques on LTE/DSRC compliant modems in order to further investigate and evaluate MHAV framework.

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